

Transportable Vitrification System

Mixed Waste Focus Area



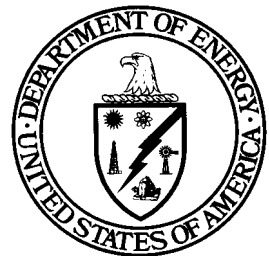
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Transportable Vitrification System

OST Reference #222

Mixed Waste Focus Area



Demonstrated at
East Tennessee Technology Park
Oak Ridge, Tennessee



Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at <http://OST.em.doe.gov> under "Publications."

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SECTION 1

SUMMARY

Technology Summary

At the end of the cold war, many of the Department of Energy's (DOE's) major nuclear weapons facilities refocused their efforts on finding technically sound, economic, regulatory compliant, and stakeholder acceptable treatment solutions for the legacy of mixed wastes they had produced. In particular, an advanced stabilization process that could effectively treat the large volumes of settling pond and treatment sludges was needed. Pressure from local stakeholders and regulatory agencies fueled the need for consideration of a vitrification process that could produce highly durable, low volume, final waste forms similar to those being developed and deployed for the more challenging high-level waste (HLW) streams. Promoters of mixed waste vitrification justified the investment of such a capital intensive, technically complex technology based on the reduced disposal costs, enhanced waste form performance, and life-cycle economic benefits obtainable through volume reduction. In addition, a mixed waste vitrification facility would not require the costly cells, shielding, and remote capabilities required of an HLW unit. Based on this need, DOE and its contractors initiated in 1993 the EM-50 sponsored development effort required to produce a deployable mixed waste vitrification system. As a consequence, the Transportable Vitrification System (TVS) effort was undertaken with the primary requirement to develop and demonstrate the technology and associated facility to effectively vitrify, for compliant disposal, the applicable mixed waste sludges and solids across the various DOE complex sites.

After 4 years of development testing with both crucible and pilot-scale melters, the TVS facility was constructed by Envitco, evaluated and demonstrated with surrogates, and then successfully transported to the ORNL ETTP site and demonstrated with actual mixed wastes in the fall of 1997. The TVS facility, as shown in Figure 1, consists of four separate modules, which combine to comprise the complete unit. Modular construction was chosen to facilitate possible transportation to the various DOE sites for multiple waste treatment deployment. During actual operations, additional temporary tent housing was required





Figure 1. The Transportable Vitrification System (in foreground) at the Oak Ridge National Laboratory (ORNL) East Tennessee Technology Park (ETTP) Demonstration Site.

upstream of the Feed Preparation Module to allow waste staging operations and accommodate additional hoppers and pumps required to feed the waste streams. As indicated in Figure 2, the four main modules consist of: (1) Waste and Additives Materials Processing Module, (2) Melter Module, (3) Emissions Control Module, and (4) Control and Services Module.

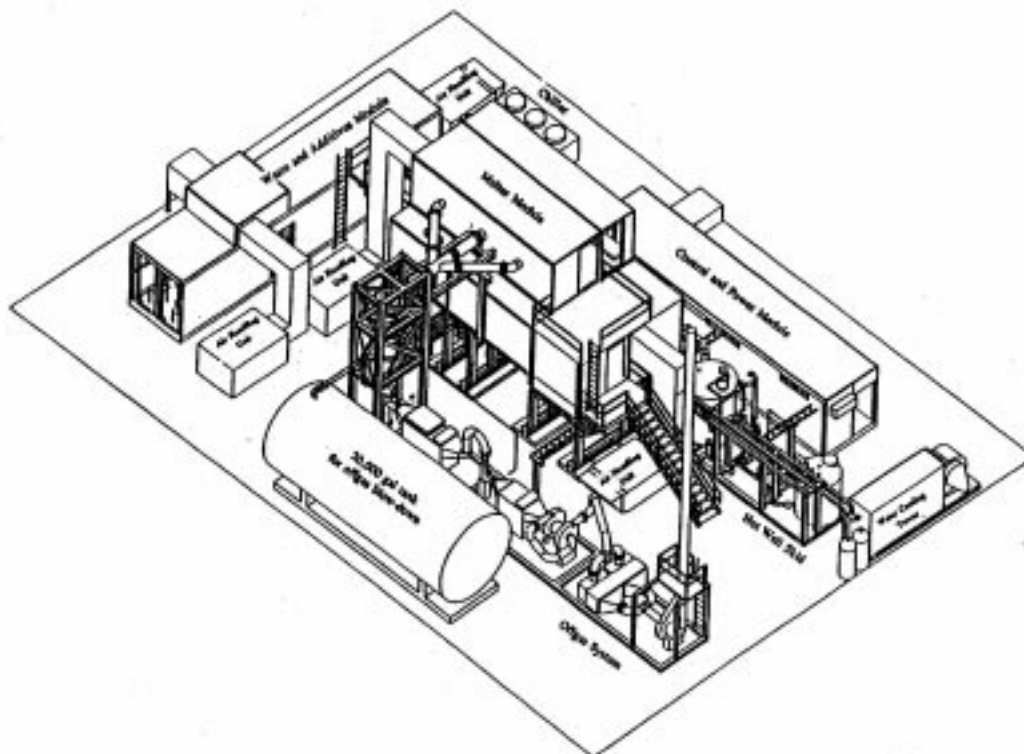


Figure 2. Isometric of the Transportable Vitrification System (TVS) Modules.

Waste and various glass forming additives are weighed, mixed, and stored in the first module before their introduction to the melter. Waste feed is accomplished with a screw auger, metering screw feeders, small hoppers for the additives, a 240-gal melter feed blend tank equipped with a load cell and agitator, a centrifugal pump, and a feed tank with agitator. The pump recirculates the final feed mixture from the feed tank through a loop, where a side stream is taken off to feed the melter at rates up to 300 lb per hour. The Melter Module consists of a joule-heated glass melter equipped with molybdenum rod electrodes and lined with "nonpremium" heavy flux contact refractory limited to 1,350⁰C. The high resistance of the glass-waste mix to the current established between the electrodes provides the required heat needed to obtain the process temperatures. Slurried feed from the first module is fed to the top of the melter by a rotating nozzle. This method distributes the feed over the melt surface to form a desired "cold-cap," which is a melting batch layer above the melt pool. The layer serves to suppress the volatilization of unwanted waste components. The melter is equipped with both a drain bay chamber and a salt tap side chamber, where corrosive unwanted salts can be skimmed off the glass surface. Waste glass is poured from the drain bay chamber into 8-cubic foot stainless steel containers for interim storage before final disposal. The containers are divided into four equal sections to facilitate faster heat dissipation (Figure 3).



Figure 3. The final glass waste form product.

Off-gas from all three main chambers of the melter enters the Emission Control Module, where systems were designed and constructed to remove over 99.99% of particulate 1 micron or less in size before atmospheric discharge. Two blowers maintain the flow of off-gas through the following components: quench tower, packed bed cooler, variable throat venturi, mist eliminator, reheater, and high-efficiency particulate air (HEPA) filters. Scrub solutions are recirculated from the cooler and mist eliminator back to the quencher and venturi nozzles. Particle saturated scrub is continually removed as blowdown, and eventually transferred to the ETTP wastewater treatment plant. As required by the TVS air permit, sampling ports are provided at the discharge stack so emission measurements can be made in accordance with Environmental Protection Agency (EPA) methods.

Nearly all of the TVS's key parameters and equipment can be regulated and monitored from the Control and Services Module. The heart of this module is a programmable logic controller (PLC), which is coupled to a graphical user interface running on an IBM compatible computer. In addition to controlling melter operations, the system tracks key data and calculates expected waste glass compositions. The power sources for the six melter zones in this module are two 800-A, 480-V three-phase electrical feeds.

Demonstration Summary

Before the actual demonstration of the TVS with mixed waste, extensive process development and testing was required at various scales. Numerous crucible size and pilot-scale tests with both surrogates and actual waste streams were done through a collaborative effort between Westinghouse Savannah River Company (WSRC), ORNL, and Clemson University. Since melter operation is highly dependent on waste and feed additive compositions, all of the surrogate testing

was done with constituents matched to those of the particular ETTP waste streams chosen for the demonstration. The purpose of additives was twofold: (1) bring the waste oxide composition into a range that ensured glass formation and (2) eliminate any reducing organics present in the waste.

The objective of this pretesting and validation was to determine acceptable ranges for the key melter parameters, waste blend ratios, overall feed composition, amount of additives, and amount of glass formers that resulted in durable glass forms with optimal waste loadings. In addition, this objective must be met while avoiding conditions adverse to the melter or its operation. Therefore, parameters and waste feed characteristics had to be determined for conditions that did not result in either devitrification (crystallization) of the melt, corrosion of the refractory, inadequate glass pouring, excessive melt temperature gradients (i.e., hot spots), foaming, shorting between melter electrodes, and/or volatilization of unwanted constituents. During this process development period it was determined that the onset of these adverse conditions was tied to one or more interdependent operating conditions or variables. Early in the development stage, testing showed these variables consisted of the glass viscosity, liquidus temperature (the highest melt temperature that forms unwanted crystalline phases), oxidation state of transition metals in the melt, and melt solubility limits for various oxides and anions of various salts in the waste feed. As a consequence, the tests were designed to study the various effects on these dependent variables by altering controllable parameters such as the feed rate, melt rate, melter temperature, and the amount and type of feed additives and glass formers. As a result of this testing, acceptable ranges for melting temperature, viscosity, metal oxidation state concentrations, and proximity to liquidus temperature were defined for the final demonstration.

After the completion of the process development and testing, an actual mixed waste demonstration on the TVS was completed in October of 1997. Waste chosen for the demonstration consisted of the B&C pond sludge and a mix of B&C pond sludge and Central Neutralization Facility (CNF) sludge. Both waste feeds were considered a challenge for the TVS due to the potential impacts on glass chemistry of their high iron and phosphorous contents. Despite difficulties with off-gas plugging and with achieving consistent waste feeding and off-gas flows, the TVS successfully vitrified 276 cubic feet of mixed waste into 112 cubic feet of glass waste form--- a 60% volume reduction despite the added glass formers. The final waste form was poured into boxes made from recycled contaminated scrap metal. The waste forms are currently in interim storage awaiting final disposition at an approved disposal site, such as Envirocare of Utah. Other key accomplishments and conclusions of the entire TVS development and demonstration effort consisted of the following:

- The TVS technology can effectively treat applicable mixed low-level waste (MLLW) sludges and homogeneous solids to meet Resource Conservation and Recovery Act (RCRA) land disposal restriction (LDR) standards based on the toxicity characterization leaching procedure (TCLP) test for the hazardous metals.
- The TVS technology can effectively treat applicable MLLW to a form that meets the 10 CFR Part 61 recommended guidelines of the Nuclear Regulatory Commission (NRC) technical position paper.
- The TVS can be operated with the feeds tested within emission limits imposed by its temporary authorization and air permit as issued by the Tennessee regulatory authority.
- The TVS can be controlled, for the range of the waste compositions tested, to achieve optimal glass waste qualities by using process control techniques established during the development phase.
- Process development is required for different waste compositions from those tested to determine the process control data and scale-up methods needed to achieve optimal glass products, consistent melter operation, and avoid adverse melter conditions.



- The transportation of the TVS is possible but costly, time consuming, and cumbersome.

Key Results

Despite its high capital costs and the need for extensive up front development, vitrification of applicable mixed wastes in facilities like the TVS has distinct benefits that result in:

- Highly durable glass waste forms with the long-term integrity favored by stakeholders, and
- Significant waste volume reduction compared to baseline and competing stabilization techniques. This volume reduction may provide a life-cycle cost advantage if significant waste volumes are vitrified.

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SECTION 2

TECHNOLOGY DESCRIPTION

This section provides a detailed description of the TVS technology and associated hardware and facilities. It also provides detailed operational parameters and conditions, as well as material, energy, skills, and training requirements. A bibliography of related works is provided in Appendix A.

Overall Process Definition

The TVS was developed, designed, and constructed to be a modular transportable unit containing only the specialized equipment pertinent to joule-heated vitrification. As such, Envitco only constructed the unique Feed Preparation, Melter, Off-Gas, and Control modules. As indicated by Figure 4, the TVS, even though complex, can not stand alone, but requires some support from the host site. The support systems are necessary to complete the entire vitrification treatment train from waste feed delivery to interim storage for the final form.

In general, these host site support systems include:

- utilities hookups, including the power transformers and cooling water sources;
- off-gas scrubber blowdown storage, treatment, and disposal;
- customized feed receiving and transfer areas upstream of the Feed Preparation Module,
- analytical support services for waste feed and glass product analysis,
- interim storage for the containerized glass forms.

The basic principles of mixed waste vitrification are founded in the fundamentals of material science and chemistry. At distinct temperatures, specific combinations of silica, calcium oxide, and sodium oxide melt and form amorphous mixtures, which upon cooling solidify into a highly durable glass. Early on, material scientists concluded that the



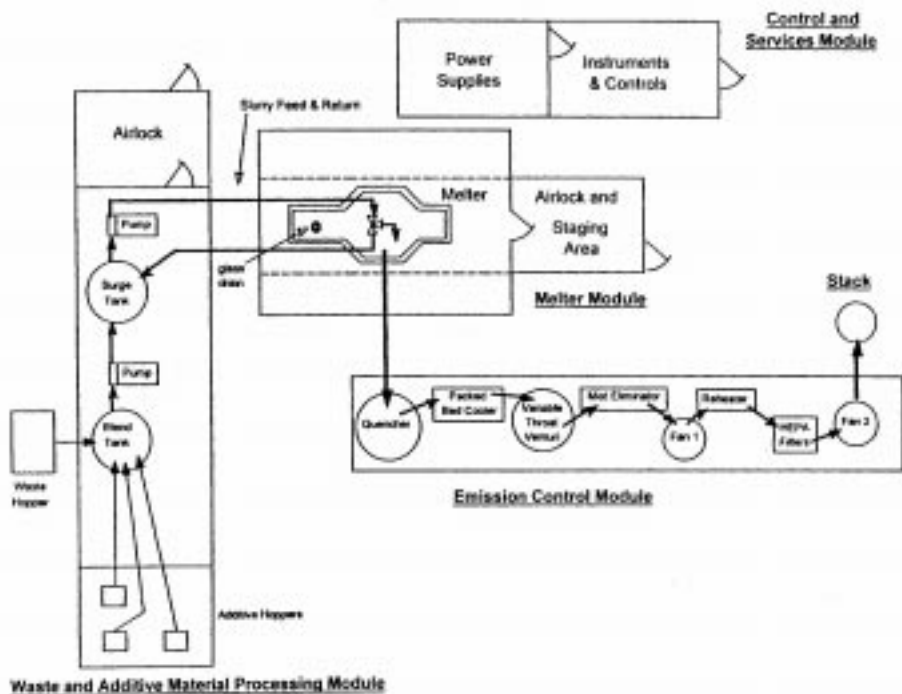


Figure 4. Schematic of the Transportable Vitrification System (TVS) Modules.

unique properties of glass made it a superior waste form for environmentally hazardous and radioactive materials. Since many of the waste materials already contained glass-forming oxides, investigators saw the benefit of mixing in additives to move the overall waste-additive-glass forming mix into the natural glass forming region for the oxides and then melting the mix at vitrification temperatures of 1,000 to 1,400°C.

The high melting temperature is achieved using a startup heat source such as natural gas, and once a conductive path between the electrodes is established, the melt temperature can then be maintained using conventional joule-heating vitrification techniques employed by the commercial glass industry. “Joule-heating” is the name given to heat energy derived from the resistance to an electric current as it is passed through low conductivity material (i.e., glass). Glass melters contain electrodes to establish the current, which in turn set up convective currents in the molten glass. These convective currents draw fresh mixtures of waste, glass formers, and other additives into the molten pool where vitrification takes place.

Nonproprietary details and specifications of the melter designed specifically for the TVS facility are outlined below:

- The refractory lined melter is contained in a shell maintained at –0.2 inches water vacuum for contamination control. The shell ventilation also includes HEPA filters.
- The glass melter is a ceramic-lined, joule-heated cold-top vessel with nitrogen purged molybdenum electrodes.
- The operating temperature range for producing molten glass is 1,150 to 1,400°C.

- Initial melter heatup and glass melting is achieved with a 500,000-BTU/h-propane burner.
- Normal operation includes use of a 100,000 BTU/h propane burner to maintain melter headspace and plenum temperatures at 315°C or greater.
- Recirculating cooling water cools the melter shell.
- The melter is compartmentalized with separate chambers for the separate pouring of glass, metals, and salts.
- The system is equipped with a remotely operable glass canister turntable and conveyor system for glass product removal.
- Glass melting and pouring can be visibly monitored with video cameras.
- Melter level measurement is by a nuclear-level gauge with a ¹³⁷Cs source.

Upstream of the Melter Module is the Waste and Additive Material Processing Module. To avoid any risk of radioactive material release to the environment, the module ventilation system is equipped with HEPA filters. In this module the waste (wet or dry) and glass forming and modifying additives are properly blended and batched for feeding to the melter. For normal as-designed situations, a screw auger transfers dry waste material from a hopper, external to the module, to a 240-gal blend tank located inside the module. This blend tank is equipped with an agitator and load cells to ensure accurate waste and additive mixes. In addition to the agitator, the blend tank can be mixed via a recirculation loop equipped with a vaneless centrifugal pump. Wet feeds require special pumps and slurry transfer systems to introduce them to the blend tank. Such was the case with the CNF sludge during the demonstration, where temporary tent structures were erected to house and contain this special transferring equipment.

Additives are fed to the blend tank via metering screw feeders. The module has a capacity for three different additives. The additives are introduced to the module in the form of ‘supersacks’ hung from forklifts above their respective hoppers. For the final demonstration, the additives chosen (as based on earlier and extensive development efforts) were the glass flux and former Na₂O and SiO₂, as well as the oxidant MnO₂.

The procedure for operation recommends first adding water to the blend tank, followed by the waste and then by the additives. The mixture is then homogenized for at least 30 minutes before being transferred to the 240-gal feed tank, which is also equipped with an agitator. Another centrifugal pump from the feed tank recirculates the feed through a loop that enters the Melter Module. A bleed stream from this loop feeds the melter.

Downstream of the Melter Module is the Emissions Control Module, which was constructed by Anderson 2000, under an Envitco contract. Off-gas from the melter enters this module through a 20-cm diameter refractory lined pipe as shown in Figure 5. Two blowers that keep the melter at 0.4 to 1.2 inches of water column vacuum, maintain flow through the off-gas system. The off-gas first enters a quencher, where it is water-cooled and some coarse particles are removed. Following the quencher, a packed bed

cooler removes moisture and finer particulate. Complete scrubbing and particulate removal is then achieved with a variable throat venturi containing a wedge shaped air –foil. The venturi is followed by a mist eliminator, reheater, prefilter, and HEPA filter, all in series before the 50-ft discharge stack. Sampling ports at the stack provide the access needed to conduct the gas and particulate measurements in accordance with the EPA. These measurements are accomplished with the following equipment and methods:

- remote gas chromatograph at ORNL, but not on the TVS site;



- remote electrochemical analyzer at ORNL, but not on the TVS site;
- EPA Method 25,
- isokinetic sampling.



Figure 5. Transportable Vitrification System (TVS) Melter with the Off-gas Emission Control Module in the foreground.

Scrub solution is recirculated from the packed bed cooler and mist eliminator back to spray nozzles in the quencher and venturi. Scrub solution makeup and caustic are added and spent; particle-laden scrub is blown down routinely. The spent scrub was stored and eventually treated onsite at ETTP's wastewater treatment facility.

System Operation

Glasses are distinguished from ceramics in that they are noncrystalline (amorphous) and soften over an elevated temperature range as opposed to having a distinct melting temperature. Consequently, the viscosity of glass can vary over a small temperature range. Presently there are over 10 types of glasses as categorized by the amount and types of oxides required to form the glass. Some of the oxides such as silica provide the glass structure and others such as Na_2O and Li_2O , referred to as fluxes, reduce melt temperature and provide the glass flow or viscous properties. Almost all the glass types contain silica and the Silica-Lime-Soda glass (SLS glass) of SiO_2 , CaO , and Na_2CO_3 , which is found in window glass, is one of the most common.

A three-phase diagram best represents mixes of three oxides and their various phases. Particular areas in the diagram represent the ranges of the various oxides that will form SLS glass when melted above the liquidus temperature and allowed to cool. A key principle of successful vitrification of waste material is to add the right type and amount of formers to move the total oxide concentration of the waste additive mix into the glass-forming region. As a consequence, operations involving feed batch, blending, and preparation are as important as operations involving the melter. Successful melt operations, therefore, require frequent feed batch analysis to ensure compositions are within ranges defined in development.

Control of certain parameters within a narrow range is also critical to successful vitrification. Important parameters to control are temperature, viscosity, the proximity to the greatest liquidus temperature, and the overall reduction/oxidation potential of the melt. These parameters must be maintained in operating ranges as determined from past process development efforts or undesirable situations could result. The ranges determined for the TVS facility and specifically for the ETTP demonstration on B&C and CNF sludge are outlined in Table 1 below. The developers of the TVS concluded that using the ratio of the amount of the iron plus-2 oxidation state, Fe^{+2} , to the total iron existing in the melt was an excellent indication of the overall oxidation state and corrosive melt behavior.

Unfortunately, the only parameters the operators can quickly control are the temperature, waste feed rate, and melt rate. Thus, the operators must be skilled enough to relate other indirect observations and results to the possible onset of adverse melting conditions. For example, changes in pourability need to be calibrated back to viscosity changes and cold spots in the melt need to be interpreted as a possible approach to liquidus temperature and subsequent undesired crystallization. In addition, foaming must be recognized as a possible indication that additives are not oxidizing the reducing organic contaminants, or the salts in the feed are greater than anticipated.

Even though feed and product glass analysis is not real time, it must be made available as soon as possible in order to adjust the amount and /or type of additives as may be necessary. These analyses will confirm if operations are inside or outside of the determined control zones to avoid corrosion, insolubility, foaming, and/or devitrification.

Table 1. Glass properties and operational ranges for the Transportable Vitrification System (TVS).

Glass property	Range	Processing concern
Melting, temperature, T_m		1,200—1,250°C Corrosion, volatility
Viscosity	20--100 poise	Pourability, corrosion, melt rate
Liquidus temperature, T_L		$T_m - T_L > 100^\circ \text{C}$ Crystallization in melter
Redox	$0.09 < \text{Fe}^{+2} / \Sigma \text{Fe} < 0.4$	Foaming, metals insolubility,
molybdenum wear		





SECTION 3

PERFORMANCE

This section provides a more detailed overview of the entire crucible testing and pilot-scale process development activities required to ensure a successful TVS demonstration on actual mixed waste. Performance of the actual demonstration is also provided. One objective of the section is to provide the potential technology end user insight into the magnitude and breadth of development that may be required to treat a specific mixed waste stream via vitrification.

Test Plan

Crucible testing was conducted at the Savannah River Technology Center and the ORNL to develop a glass formulation suitable for incorporating both B&C pond sludge and CNF sludges, and compatible with the design of the TVS joule-heated melter. Based on a significant history with developing formulations for HLW glasses at Savannah River, initial testing was directed toward characterizing melt viscosity, phase stability, and compatibility with the heavy flux glass contact refractories used in the TVS. Formulation development centered around a three component system: Na_2CO_3 , Li_2CO_3 , and SiO_2 , which would take advantage of the attributes of a mixed alkali glass and still be within the limitations of the melter feed system that was equipped to add three separate dry components. The combined alkaline-oxides have been demonstrated to be pourable at lower melting temperatures while maintaining excellent durability. A reference glass consisting of 7.5 wt% of each of the alkaline-oxides, 35 wt% SiO_2 , and 50 wt% of either of the sludge surrogates became the basis for crucible testing, and follow-on work at Clemson in the TVS melter through March of 1995.

Analysis of the actual B&C pond sludge material in June of 1996 showed total organic carbon levels of 0.36—2.4 wt%, which would cause the glass to be too reducing for operation in the TVS melter. Significant testing followed to determine that a MnO_2/C mole ratio of about 1.5 would be necessary to control the redox of the melt to within acceptable limits. Secondly, the MnO_2 component could be no greater than 10 wt% due to the potential for foaming. The requirement for an additional component eliminated the use of Li_2CO_3 due to the constraints posed by the feed system.

Testing with CNF sludges at waste loadings up to 40 wt% indicated possible formation of a separate phosphate glass phase at levels above 20 wt%, so a conservative limit of 15 wt% was set for this waste. Melts made with combined B&C and CNF sludges confirmed this finding, indicating that the CNF component could make up no more than 40% of the 50 wt% total waste loading.

Development Plan

Pilot-scale melter development testing was conducted at the Clemson University Department of Environmental Systems Engineering (CESE) using the EV-16 unit with a capacity of 2.6 ft³ and the MM-005 “mini-melter” with a capacity of 1 ft³ at the Clemson Environmental Technologies Laboratory (CETL) facility. These melters were both slurry fed. In the initial demonstration, using the EV-16 unit, surrogate B&C sludge was fed at a loading of 50 wt% with the original additive recipe (35% SiO_2 , 7.5% Na_2CO_3 , and 7.5% Li_2CO_3). The glass produced readily passed TCLP with all metals nondetectable in the leach solution, and Product Consistency Testing (PCT) indicated the glass was as good as the baseline glass for HLW. The PCT is not required for LLW glasses, but the results indicate that the glass was very durable, and the formula appeared to be readily processed in the small melter.

By this time in the flowsheet development, the analytical results indicating the higher than expected organic carbon levels in the sludge were available, and a second round of testing was conducted in the EV-16 melter using a B&C sludge surrogate spiked with 2 wt% activated carbon. Melt recipes were designed to test additions of MnO_2 at three different levels to bracket the concentration required for good control of



redox conditions. Though the MnO_2 was added to the recipe, the original mixed alkali composition was just amended with the fourth component, and both Na_2CO_3 and Li_2CO_3 were used in the recipe. Some problems were encountered during the runs because feed rate was limited by foaming in the melter when, as predicted by the crucible studies described above, the MnO_2 levels were too high. Cooled glass was amorphous, suggesting that the glass formula was stable and not particularly sensitive to devitrification.

A third series of tests was planned using the “mini-melter” to evaluate feeding a mixture of surrogate B&C sludge with actual CNF waste. The same recipe as that used in the EV-16 tests with B&C sludge alone was used as a checkout run in the new melter before the combined sludge testing. Temperature control was immediately a problem in the small melter, with the installed thermocouple reading several hundred degrees low. Higher temperatures shifted the redox conditions to more reducing conditions. The CNF waste may also have been more reducing than expected based only on carbon content. Finally, the glass recipe used was in doubt because the Na content diminished over time indicating a discrepancy in the feed mixture or perhaps loss by volatility due to the temperature excursions during testing. Ultimately the melter failed, highlighting the need for accurate temperature control during operation of the TVS.

Demonstration Plan

Beginning in July of 1997, the TVS melter was operated for 3 months to conduct the actual demonstration with ETTP mixed waste sludges. The plan was to start up the system with glass cullet (discarded bottle glass) and follow this with enough SLS surrogate feed to produce over 15,000 lb of surrogate glass waste. After the surrogate run, over 16,000 lb of B&C pond sludge and combinations of B&C pond sludge and CNF sludge was vitrified. The original plan was to treat over 175,000 lb, but this capacity could not be achieved due to funding constraints and schedule delays. The only major modifications required to complete the TVS demonstration dealt with hardware and operation procedures for unloading waste drums into the first Waste and Materials Processing Module. The addition of a duplex strainer system to remove large waste feed particles from a slurry feed was one of the major engineered changes. The addition of air blasters to the main feed hopper was another.

The main goal of the demonstration was to validate and verify that the TVS could be controlled within the process control parameters outlined by Table 1, while at the same time producing compliant waste form glass suitable for disposal. Secondary goals of the demonstration dealt with meeting emission requirements set forth by conditions specified by the temporary authorization (TA) permit. Details of these requirements and the emission test results are described in Section 6.

The goal of maintaining process control was, as expected, accomplished by adjusting and altering waste feed blends and additives based on waste, feed blend, and glass analyses. Additional information in regard to melting behavior was also used to effect changes. Empirical models that had been developed by WSRC were used to predict Table 1 values based on feed and glass compositions. Similar models had been deployed earlier for the HLW vitrification facility at Savannah River and had adequately predicted values for such key parameters as melt viscosity, redox ratio, and liquidus temperature. These models served as tools for TVS operators to determine batch adjustments to keep the glass properties in the ranges of Table 1. Basically, glass compositions were altered by balancing additions of waste (dry B&C pond and wet CNF sludge), the two glass forming additives, SiO_2 and Na_2CO_3 , and the oxidizer, MnO_2 , which was added for redox control.

Because glass sample analysis could not be turned around quickly enough and it was not practical to shut down the melter for every batch, necessary feed adjustments could only take place every three to four batches. These adjustments were made using the models and were based on the outcome of glass sample analyses from three feed batches earlier. Even though this lag time appeared to be a limitation in controlling the process, pour glass sample analyses confirmed that glass composition was controlled within the glass-forming region of the SLS system.



Treatment Performance

Even though the demonstration experienced some problems with off-gas plugging and high inlet quench temperature, general melter operations occurred without significant incidents and overall glass quality was excellent. Cadmium, chromium, and mercury, which ranged up to 5.0, 82, and 21 mg/kg in the feed respectively, were well retained in the glass waste form as indicated by TCLP leach results that were 100 times below the regulatory limits.

The surrogate portion of the demonstration consisted of 14 separate feed batches. The first 13 batches were actually a surrogate of a silica-lime-lithia-soda glass, where the dry calcium carbonate (lime) additions tested out the dry feed system installed to feed the B&C pond sludge. After the surrogate runs, the TVS successfully vitrified 20 different batches of mixed waste feed. The first four batches consisted of 2,500 lb of B&C pond sludge and the next 16 batches consisted of waste blends made up of ~5,900 lb of B&C pond sludge and ~7,800 lb of CNF sludge. For initial batches involving waste blends, the mix ratio of CNF to B&C ranged from ~ 1: 2 to 3: 1. However, after Batch 7, the ratio was held fairly constant at ~5:4 as a consequence of obtaining desired melter operations and glass quality. In all cases actual waste loadings in the feed was ~46.5% on a weight basis and the overall volume reduction of the waste was ~60%. As a result of the demonstration on actual waste, 14 separate glass containers were filled with ~17,162 lb of waste glass. This constituted about two melter volumes. An additional eight containers were then poured with surrogate and glass cullet to flush out the system.

Key System Parameters

Key melter data obtained by the TVS demonstration are listed below.

Melter vacuum	0.9 inwc
Total air leakage in main, glass, and salt chambers	400 scfm
Plenum temperature during feeding	600–700°C
Steady state glass production rate	~50 lb/h
Melter feed rate	0.65 gpm
Temperature range of operation	1,170–1,300°C
Desired temperature range	1,200–1,250°C
Recommended heatup and cooldown rates to protect refractory	25°C/h
Temperature required to reach continuity with electrodes	600-700°C
Observed refractory and electrode corrosion and wear	none

Limitations/Potential Problems

The melter performed well during the demonstration. However, the melting rate decreased during the course of the demonstration, resulting in a lower than expected average throughput rate. Expected throughput was ~900 kg/day glass while the actual average throughput was half that at ~450 kg/day. This decrease in melting rate is attributed to the high iron content of the mixed waste streams selected. This resulted in dark glass having less than adequate heat transfer characteristics to facilitate faster melting and pouring.

The TVS is also limited as a result of the materials chosen for its construction. The refractory is of a nonpremium type and is highly susceptible to corrosion if temperatures consistently exceed 1,350°C or the reduction - oxidation conditions (redox state) in the melt are not within operating limits. In addition, the



manner in which the refractory was installed is also limiting. The refractory is kept in place by plates, which upon excessive melter thermal cycling, become loosened and misplaced. These misplaced refractory shell plates, if not properly retorqued, can lead to destructive glass leaks. Such was the case in November of 1996, when upon flushing the melter with bottle glass cullet after B&C pond surrogate waste testing at ORNL, over 1 ton of molten glass leaked into containment below the melter, burning hoses and instrument lines. Recovery from the leak took over 6 months.



SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

This section addresses in more detail the types of mixed waste streams that TVS treatment is most amenable to. The section also compares the TVS technology to other baseline and competing low-temperature stabilization technologies and defines the status, commercial availability, and maturity of the TVS technology.

Baseline and Competing Technologies

The baseline stabilization technology competing with mixed waste vitrification is cementitious solidification, since type II Portland cement is one of the most widely used techniques for the treatment and ultimate disposal of hazardous, low-level, and mixed wastes. The technique is commonly referred to as 'grouting' and has been successfully deployed for the treatment of low-level radioactive wastes for decades. There is a wide range in the composition of the various cementitious materials and admixtures used as solidification agents for wastes. Examples of these include blast furnace slag, other pozzolans, five types of Portland cements, high alumina cements, and masonry cements. Specifically, however, ordinary Portland cement is composed chiefly of three oxides: silica [SiO_2], lime (CaO), and alumina (Al_2O_3). When Portland cement is mixed with water and waste, its constituent compounds undergo a series of hydration chemical reactions, which causes it to harden or cure. The chemical reactions occurring during the setting, hydration, and aging of a Portland cement-water-waste mixture are complex, interrelated, and not completely understood.

Portland cement grout waste forms are designed to withstand the acetic acid extraction of the TCLP leach test by neutralizing the acid, resulting in a high final pH and low RCRA metal concentration. The natural high pH of grouts offers a satisfactory low solubility environment for many metals. Even if straightforward hydroxide chemistry has problems meeting the regulatory limit, the metal may be stabilized using other anions; e.g., chloride may be added to a grout to stabilize silver. Tailoring the grout with slag and pozzolans is desirable for reducing the solubility of the hazardous and radiological components, and increasing the waste loading, strength, and durability. Sludges resulting from wastewater treatment and thermal air pollution control systems (APCS) are among the physical waste types often stabilized with grout systems. Grout cannot handle greater than trace amounts of organics and has trouble setting and curing when the waste stream contains appreciable quantities of salts, unless specifically tailored to handle them.

Unlike vitrification, grouting is a room temperature process that produces no off-gas emissions and requires moderate levels of process development to validate an acceptable formulation. Usually the equipment to deploy cementitious stabilization is inexpensive, simple, of low maintenance, and readily available. Therefore, in comparison to vitrification, the short-term capital and operation costs for grouting are substantially lower. However, the stakeholder perception of grout's integrity in comparison to that of glass is usually unfavorable. The layman usually has firsthand experience on the deterioration of construction concrete over time, and extrapolation of this experience to its use as a mixed waste form can make acceptance difficult. In addition, lack of adequate process control and/or inappropriate grouting of DOE streams in the past has created a negative impression of grouting technology among some DOE program managers.

The most frequently cited problem with grout stabilization/solidification using Portland cement is the associated volume increase of the final waste form above that of the original unstabilized waste. Volume increase can be minimized by adding the minimum amount of additive to pass the TCLP test at the expense of strength and stability of the final waste form. However, the waste loading and volume reduction levels can not reach those achievable with vitrification. On the other hand, system availability, maintenance, and air emissions may be significant balancing considerations if presented openly and fairly to stakeholders.



There are many mixed waste stabilization/solidification technologies at various stages of development that could be considered as competing with joule-heated vitrification facilities like the TVS. Numerous tests with low-temperature stabilization techniques involving ceramics and polymers indicate that greater waste loadings (than those achievable with conventional Portland cement) are possible with even the troublesome salt containing wastes. In addition, alternatives involving thermal-sintering techniques also may lead to acceptable waste forms with considerably more volume reduction compared to that achievable with grouts. Mixed waste stabilization methods currently in the later stages of development include phosphate-bonded ceramics, enhanced concretes using proprietary additives, and several methods provided by commercial vendors. Low temperature methods like phosphate bonded ceramics not only provide a low porosity ceramic barrier, but render the RCRA metal less hazardous by converting it to the low solubility phosphate salt. Microencapsulation techniques involving polyesters, polyethylene, and polysiloxane have been demonstrated on surrogate and/or actual wastes that would otherwise be amenable to vitrification.

Sintering differs from vitrification in that only melting at grain phase boundaries occurs without the complete amorphous restructuring that takes place in glass formation. Like vitrification, sintering occurs at temperatures over 1,000°C and can emit volatile hazardous metals. Even though densification is possible for some additional volume reduction, slight volume increases usually occur. However, waste loadings as high as 80% are possible. The equipment for sintering is less complex than vitrification, but more complex than grouting. For a typical sintering process, grinding, mixing, and extruding equipment is required as well as ovens, calciners, and off-gas treatment systems. For most waste streams, application of sintering methods will require an extensive process development effort involving statistically designed experiments.

Recently developed polymeric methods using batch mixers or extruder systems are currently available. These low- temperature microencapsulation techniques do not truly stabilize the waste, but create an impermeable barrier between the hazardous components in the waste and the environment. Waste loadings in these organic media are usually on the order of 50% for many troublesome wastes, such as incinerator fly ash or those containing appreciable salts. This value is nearly twice that achievable with conventional cement grout methods. Once again however, these methods can not achieve the volume reduction of vitrification, or produce disposal forms having the long-term durability associated with glass. To their advantage, these processes emit little or no off-gasses and use equipment much less complex and expensive than that for vitrification.

If costs were the only factor, the choice to use the competitive technologies of ceramics, polymers, or sintering methods over that of vitrification would depend on the volume of waste to be treated. For each alternative stabilization case there will be a distinct cost crossover volume where vitrification becomes more economically feasible. At relatively low waste volumes the cost savings that are a consequence of the low volume glass waste forms cannot overcome the high fixed capital cost associated with the complex melter systems. To the contrary, if sufficient volumes are treated, the large savings in the volume dependent disposal cost will recover the original high investment.

Technology Applicability

The TVS facility and its associated technology was originally and specifically developed and designed for the treatment of pond and wastewater sludges containing inorganic hazardous metals. For the actual demonstration, specific ORNL ETP waste sludges (B&C pond and CNF) were selected and treated separately or as a blend. A breakdown of the demonstration sludges' composition is provided in Table 2 and the characteristics of selected waste feed blends and additives batched to the TVS during the actual demonstration are provided in Table 3.

In general, the B&C ponds were used at the old K-25 gaseous diffusion plant site (now the ETP) as holding and settling ponds for coal pile runoff, effluents from decontamination, plating, diffusion barrier manufacturing facilities, and diffusion cascade blowdown. The B pond was a flowthrough holding pond, and the C pond was a retention basin that received dredged sludge from pond B. The sludge is designated mixed waste and carries the RCRA hazardous code F006 for the metals that reside in the waste from past plating operations. As a consequence, the waste must be stabilized to meet concentration based standards for the cadmium, silver, cyanide, lead, and chromium present. A portion of the pond waste and soil was removed and stabilized in concrete, but the majority of it was just removed and placed in drums. The CNF sludge is from the ETP CNF, which treats wastewater originating from a

Table 2. Transportable Vitrification System (TVS) demonstration waste feed compositions.



Component	B&C pond (wt%)	CNF sludge (wt%)
Al ₂ O ₃	11.148	2.815
BaO	0.033	0.117
CaO	14.692	14.272
CdO	<0.001	0.006
Cr ₂ O ₃	0.053	0.107
CuO	0.048	0.368
Fe ₂ O ₃	7.363	34.027
K ₂ O	1.235	<0.531
Li ₂ O	0.008	<0.006
MgO	1.003	0.885
MnO ₂	0.174	0.304
Na ₂ O	0.209	0.789
NiO	0.311	0.056
P ₂ O ₅	1.020	19.500
PbO	<0.015	0.354
SiO ₂	46.000	6.375
SrO	0.015	0.033
TiO ₂	0.776	0.305
UO ₂	0.136	1.906
ZnO	0.34	1.051
Total oxides	94.297	83.868
Total carbon	3.950	2.214
TOC	2.425	2.214
Chloride	0.043	0.200
Fluoride	2.490	0.120
Nitrate	0.208	0.190
Sulfate	0.938	2.000
Phosphate	0.630	23.000
% solids	97.350	17.10
% calcine	91.200	14.20

Table 3. Selected demonstration Transportable Vitrification System (TVS) feed batch information.

Batch Number	2	4	5	7	9	10	11	12	14	15	16	18	20
B&C oxide wt%	46.2	46.7	42.7	31.3	38.5	38.5	38.5	38.6	38.5	38.7	39.0	38.5	38.7
CNF oxide wt%	0	0	3.6	15.6	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
Waste Loading	46.2	46.7	46.3	47.0	47.1	46.8	46.8	47.0	46.9	47.1	47.3	46.8	47.0
B&C (lb) ^a	628	641	384	272	356	375	385	377	349	376	345	329	375
B&C Cumulative (lb)	1,265	2,500	2,884	3,433	4,169	4,544	4,929	5,306	6,008	6,384	6,729	7,475	8,372
CNF (lb) ^b	0	0	186	770	430	460	473	462	428	460	417	404	584
CNF Cumulative (lb)	0	0	186	1,743	2,637	3,097	3,570	4,032	4,893	5,353	5,770	6,686	7,786
Na ₂ CO ₃ (lb)	240	238	155	139	146	156	161	156	144	154	141	137	194
SiO ₂ (lb)	306	336	251	255	254	270	278	272	238	255	231	226	323
MNO ₂ (lb)	229	195	93	74	96	104	105	101	113	119	108	105	152
NaNO ₃ (lb)	0	0	0	18	18	20	28	19	22	22	21	22	33
B&C oxides (lb)	507	517	310	220	287	303	311	304	282	303	278	266	383
CNF oxides (lb)	0	0	26	109	61	65	67	66	61	65	59	57	83
Additives oxides (lb)	590	591	390	372	391	417	429	417	388	414	376	367	525
Oxide weight/batch (lb)	1,097	1,109	726	700	740	785	807	787	731	783	714	690	991
Cumulative oxide (lb)	2,202	4,338	5,064	6,482	8,818	8,803	9,610	10,397	11,865	12,648	13,362	14,925	16,795
Batch end feeding date	9/27	9/29	10/1	10/4	10/6	10/7	10/8	10/9	10/11	10/12	10/13	10/16	10/19
Glass Fe ⁵² /Fe total ^c	0	0.15	0.23	0.43	0.39	0.38	0.33	0.31	0.34	0.42	0.50	0.46	0.35

^aB&C as batched, overall loss on drying plus loss on ignition 19.3%, nominal analysis assumed in calculating B&C oxide lb.

^bCNF sludge, 17% solids, overall loss on drying plus ignition 85.8%, nominal analysis assumed in calculating CNF oxide lb.

^cFe⁵²/Fe total^c ratio measured on glass samples taken at end of feeding the indicated batch.





mixed waste incinerator, steam plant, and metal finishing and cleaning facilities. The CNF, which uses a coprecipitation and flocculation process involving lime and ferric sulfate, produces waste sludge containing calcium carbonate and ~70% moisture. The mixed waste CNF sludge stream contains over 30 listed codes; most of them derived from the TSCA incinerator blowdown influent

Even though not selected and directly treated during the TVS demonstration, numerous other ORNL sludge waste streams were evaluated and deemed potential TVS candidates. The origins of these wastes were from the Y-12 Plant's Central Pollution Control Facility, West End Treatment Facility, and the ETTP's K-1232 Corrosive Liquid and Heavy Metal Treatment Facility. These wastes mostly consisted of electroplating wastewater treatment residues such as oily sludges, wet filter cake, and dry filter sand. Lagoon sludges and slurries were also part of this inventory.

For the TVS process to be effective for a given waste type, it is recommended that the waste stream contain sufficient amounts of glass forming oxides and be deficient in reducing organic contaminants and corrosive foam-causing salts. The waste material may be "contact-handled" dry sand-like or particulate material or a wet sludge, but should be homogeneous, primarily inorganic, and contain significant quantities of glass forming silica, alumina, and/or iron oxide. Since the current TVS has no radiation shielding, it cannot be used for treatment of remote handled wastes. Based on the above waste stream requirements, the following other waste groups would also be low risk candidates for stabilization in joule-heated vitrification facilities like the TVS: incinerator blowdown sludge, low carbon incinerator hearth and fly ash, inorganic paint waste, low-mercury crushed light bulbs, and inorganic laundry sludges. In theory, the TVS technology is capable of treating most of the 30,000 cubic meters of inorganic sludge, soil, particulate, crushed debris, and homogeneous solids estimated to exist in the DOE weapons complex nationwide. Mixed waste stabilization/solidification through vitrification is possible as long as sufficient process development is conducted to identify the correct additives and key process control parameters. However, the practical application of vitrification to a waste stream will also depend on a number of nontechnical, economic, and social factors as well. As will be qualified in later sections, factors involving DOE's waste treatment privatization efforts, difficulties associated with offsite waste shipments to the TVS, quantity of waste to be treated, the availability of competing and baseline technologies, and the unwillingness to site off-gas emitting technologies (despite their potential for superior waste forms) all affect the decision to deploy vitrification.

Technology Status and Maturity

Early development of the TVS technology included crucible-scale studies, including investigations of complex glass chemistry under varying vitrification conditions. These studies were performed with waste surrogates at DOE's SRS and with actual mixed wastes at the DOE's ORNL. This developmental testing took place between 1993 and 1995 under sponsorship by DOE's EM-50 program and was conducted by scientists and engineers of WSRC, the SRS contractor, and LMES, the ORNL contractor. Based in part on the results of this testing, pilot scale development of the technology was conducted between 1995 and 1997. This pilot-scale testing involved surrogate wastes with a smaller scale melter, EV-16, at DOE's Industrial Center for Vitrification Research, and also involved the processing of surrogate and actual mixed wastes in a mini-melter at the CETL. Concurrent with this activity, a private company, Envitco, was contracted to construct the full-scale TVS in July of 1995.

Fabrication of the modules and its components occurred at Envitco's subsidiary facility, Dreicor, Inc., in Erwin, Tennessee. Following acceptance testing, the completed TVS unit was dismantled and shipped to Clemson, South Carolina. There the TVS was reassembled for both surrogate and checkout testing by WSRC and Clemson University personnel. At the time of checkout/surrogate testing (between December 1995 and March 1996), plans were also formulated to prepare the chosen ORNL site for the TVS demonstration on actual mixed waste. Based on results of the surrogate testing and ORNL site-specific requirements, TVS modifications at Clemson were completed, followed by shipment to the prepared ETTP demonstration site at ORNL. In the fall of 1996, LMES took full responsibility and possession of the TVS unit, but still relied on technical assistance from WSRC. In September of that year, with cosponsorship of both EM-50 and EM-30 at ORNL, the unit was started up again for surrogate and shakedown testing. In November it was placed in cold shutdown mode to address permitting issues and make refractory modifications to address the cause of a leak.



Less than a year later, after obtaining a TA permit from the Tennessee Department of Environment and Conservation (TDEC), processing of actual mixed waste was demonstrated between September 24, 1997 and October 20, 1997. During this time, 8,372 lb of B&C pond sludge and 7,787 lb of CNF sludge (a total of 276 cubic feet of mixed waste) was vitrified into 17,338 lb of glass with a volume of 112 cubic feet.

The TVS technology is now available to DOE complex end users with sufficient quantities of inorganic sludges, homogeneous solids, and soils. It is particularly applicable to end users in need of a waste treatment method that produces final forms with both superior long-term performance and volume reduction currently unobtainable with baseline cementation methods, or competing alternative stabilization processes. Low temperature alternative stabilization technologies that have recently been developed, such as those involving ceramics or polymers, have achieved higher waste loadings than those obtained with cement grouting. However, except for unique applications, these alternatives have yet to provide the volume reduction and resistance to leaching achievable through joule –heated vitrification units like the TVS. Situations involving relatively large quantities of homogeneous mixed wastes may justify the capital expense to deploy TVS over the alternative baseline and competing technologies, since the economic benefits associated with the volume dependent life-cycle disposal costs will not be realized unless large inventories are treated. System availability, maintenance costs, potential air emissions, and process sensitivity to feed variability should also be considered in comparing a high temperature process to a nonthermal system.

Patents/Commercialization/Sponsor

As a consequence of the EM-50 and EM-30 sponsored development and demonstration effort as provided in this ITSR, the TVS or its technology are now available for deployment on other applicable mixed waste streams throughout the DOE complex. Future plans currently under consideration for the TVS facility include, but are not limited to: (1) continued system use by DOE-OR to treat secondary wastes from primary ORNL waste treatment facilities, (2) contracting or subcontracting of the TVS to treat ORNL and/or other complex-wide waste streams, (3) privatization of the TVS to potential future vendors bidding on a large ORNL privatization effort, or (4) maintaining the TVS as a backup to proposed privatization technologies. Many of these options will require resolving intellectual property rights issues associated with specific parts of the TVS. These rights are Envitco-specific and will have to be resolved through discussions with the TVS manufacturer. For non-DOE commercial applications, end users may also obtain the technology and reproduce the facility for their specific application through a contract or license with Envitco.

The unique TVS design, melter construction, and the specifics of its melter operation are proprietary to Envitco. Potential end users interested in deploying the system must ensure that certain private information is protected. In addition, certain competitive melter companies are prohibited from operating the TVS, if ORNL competes the use of TVS to treat ORNL facility or other offsite waste.

The future specific uses of the TVS are currently under evaluation by DOE EM-30 personnel at ORNL. Interested end users are advised to contact the MWFA, or the DOE ORNL Program Manager for details on issues associated with procuring the TVS. At this point, further contact with Envitco will be established if necessary. Since the TVS was developed with DOE funds, no Envitco license arrangements are necessary to continue to treat DOE mixed waste. However, treatment of non-DOE waste would require an arrangement with Envitco involving either a contract or license.



SECTION 5

COST

The following cost methods, data, and estimates are based on an ORNL analysis conducted after the demonstration. End users are to be advised that future use costs for TVS should be lower than reported. The first demonstration costs included significant development and construction costs, some of which will be recovered as the TVS is continued to be deployed.

Methodology

Life-cycle cost calculations were evaluated primarily from a perspective of only operating the TVS. Certain life-cycle cost items, as well as recovery of invested costs, were not incorporated into the cost calculations. The calculations involved separate cost estimates for capital, transportation, site preparation, development, and decontamination and decommission expenses incurred before the demonstration operations. Estimates for current operational costs, current demonstration analytical costs, and analytical costs for future TVS operations were also determined. The original ORNL cost evaluation included baseline grouting operations as a means of a cost comparison to the TVS.

Cost Analysis and Conclusions

Capital costs, including all the equipment for the TVS plant, have been evaluated at \$5M. Transportation costs for moving the equipment to ORNL were approximately \$20K. Installation costs at ORNL were estimated at \$420K. The site preparation costs at ORNL were ~\$350K, including preparation of the pad area and provision of needed services. The development costs include the laboratory, bench, and pilot-scale testing needed to characterize the waste and to determine its required processing conditions and process control parameters (including glass formulation). It is assumed that this quantity will be a maximum for the first demonstration. However, during normal operations, this cost can be spread among the various plants constructed for the vitrification. It is recommended that a new investment in vitrification include at least \$1M for development costs. Appendix B provides a list of the MWFA contracts that provided development contract to ORNL and SRS. Decontamination and decommission costs are assumed to be also \$1M.

Operational costs for the TVS were divided into both fixed and feed-dependent components. Because the melter is kept hot even when no waste is being fed to the system, there are certain cost components that will still be incurred. These include such items as electricity, propane, and nitrogen. The costs of personnel will also be a fixed cost in most applications. For fixed items, the operational costs were based on the time the TVS would be up regardless of the amount of waste fed to the system. By increasing the feed rate to the system and therefore also reducing the amount of time required to finish a waste treatment campaign, these costs can be reduced. Operational costs also include variable costs. These costs are directly dependent upon the amount of waste treated and include such items as the amount of glass additives and the number of analytical samples. Variable cost items are unaffected by the amount of time it takes to finish a campaign and are determined by their ratio to the waste fed. The amount of waste also affects the life-cycle cost comparison to that of the baseline grout method. More waste leads to lower disposal costs for vitrification as a result of the volume reduction capabilities of glass in comparison to the volume increase consequences of grouts.



Actual operating costs of the TVS demonstration activities were high, at approximately \$90/kg of original waste. However, this figure does not represent the operating cost of a steady-state normal operating system. Analytical expenditures during the demonstration were higher than is assumed to be necessary for steady-state operations in the future. Depending on the amount of waste treated, the steady-state TVS operating costs can range from \$10/kg of waste to \$44/kg of waste. The cost can be lowered to a more manageable range of \$7/kg to \$17/kg of waste for analytical costs provided by a different chemical analysis provider. The average analytical cost incurred during TVS mixed waste demonstration was high at \$13.80/kg of waste. This cost includes analytical expenses incurred during demonstration activities that would not be present in normal operations. A more realistic estimate of the analytical costs is ~\$3/kg. This cost is based on analytical requirements for normal operations and commercial laboratory prices.

Under one scenario, the cost analysis indicated that vitrification becomes cost-effective over the baseline grout process at waste feed rates of over 100 kg/h if the waste is delisted for cheaper disposal, and transportation and disposal costs are considered in the evaluation. This study assumed a grout cost of ~\$12.00/kg and determined that under these conditions vitrification cost was as low as \$9.00/kg.



SECTION 6

REGULATORY AND POLICY ISSUES

This section presents current and anticipated regulatory requirements that an end user of vitrification technology would have to meet before mixed waste treatment and during any development phases. The specific regulatory requirements and their associated issues that pertained to the TVS effort are also described.

This section also presents an analysis performed by the MWFA that assesses the various risks involved upon deployment of the TVS and pertinent stakeholder responses to the siting of a mixed waste thermal treatment facility in a given community.

Regulatory Considerations

The major regulatory objective of developing and deploying the TVS is to produce final waste forms that consistently meet applicable LDR treatment standards for the hazardous metals and organics in the wastes. Treatment of hazardous waste or mixed waste must meet the applicable RCRA 40 CFR (Code of Federal Regulation) §268.40 LDR treatment standards, including treatment of any underlying hazardous constituents to meet the universal treatment standards (UTS) contained in 40 CFR §268.48. Nuclear Regulatory (NRC) 10 CFR 61 waste form testing will also be required for final disposal in NRC licensed sites. Individual commercial and DOE disposal sites may have additional site-specific requirements, including specific radionuclide limitations that may also affect qualification of the final waste form.

Additional regulatory requirements, including permit and license requirements that were necessary for implementation of the TVS technology for mixed wastes included the requirements listed below. These requirements would need to be considered by potential future TVS end users or any other users that would deploy a similar vitrification technology:

- A National Environmental Policy Act (NEPA) review for implementation at federal facilities. (A categorical exclusion is likely to apply for treatability studies). At DOE facilities, this review includes an initial environmental checklist that assists in determining if a more detailed environmental assessment or environmental impact statement is required.
- A radioactive material license from NRC or its applicable agreement state for non-DOE facilities, and for DOE facilities to be regulated by NRC or the agreement state.
- RCRA notifications or approvals of applications submitted to the regulatory agency based upon the scale and purpose of the process and the capability of the process to perform the required treatment of LDR wastes. These may include:
 - Notification to applicable regulatory agency (state or EPA) for treatability studies.
 - Approved Variance or Determination of Equivalent Treatment to allow disposal of treated wastes and residues if the waste is subject to a specific technology based LDR treatment standard.
 - Waste Analysis and Treatment Plans for wastes treated by a generator under 40 CFR 262.34 or under 40 CFR 264 or 265 for wastes to be treated at permitted facilities.
 - Issued RCRA Part B permit or permit modification by the applicable regulatory agency (state or EPA) for treatments that are not treatability studies. Currently, a risk assessment for emissions and effluents is required to be included as part of the permit or modification application. Such a risk assessment was required for the temporary authorization permit issued by the TDEC. If an off-gas combustion capability were added to control emissions of hazardous organic constituents, the facility may be subject to 40 CFR 264 Subpart O RCRA permitting requirements for hazardous waste incinerators.



- Clean Air Act (CAA) permitting
 - National Environmental Standards for Hazardous Air Pollutants (NESHAPs) applicability review to determine the need for NESHAPs permitting or air/emissions monitoring for any operation that involves potential releases of particulates, gases, or vapors that may contain radionuclides or other regulated hazardous air pollutants. The regulatory approvals and submittals identified in that review must be in place to operate the facility. Even though not applicable at the time of the TVS construction and operation, forthcoming Maximum Achievable Control Technology (MACT) emission limits (including standards for dioxin, mercury, particulate matter, carbon monoxide, hydrocarbons, and HCl stack discharges) and associated requirements for continuous emissions monitoring of particulate emissions are to be expected. Especially if the TVS facility uses off-gas combustion to control emissions of hazardous organic constituents from the waste feed. These MACT NESHAPs standards may also be applied by state regulatory agencies to thermal mixed waste treatment technologies, like vitrification, via the RCRA permitting provision. If applicable, development of appropriate off-gas treatment technologies and monitors to meet MACT compliance may take considerable resources.
 - National Ambient Air Quality Standards (NAAQS) and New Source Performance Standards (NSPS) applicability evaluation and PSD review to determine the need for Permit to Construct application or air permit modification as applicable. Required permits and permit modifications must be issued by the applicable regulatory agency.
 - Treatment and permitting for nonhazardous liquid effluent/wastewater (such as nonhazardous coolant water) to meet NPDES, publicly owned treatment works (POTW), or other applicable wastewater disposal requirements.
 - Treatment and disposal requirements for other secondary waste streams, e.g.,
 - Spent pre-HEPA, HEPA filters
 - Spent refractory
 - Scrubber blowdown related wastes
 - Miscellaneous maintenance, repair, and operations waste
 - Personal protective equipment.
- State- or locality-specific requirements, such as those involving siting, zoning, historic preservation, and other laws and regulations that may require additional permits and licenses.

Because of the TVS development status and its unique design, not all of the current and proposed rules and associated guidance for hazardous waste combustors or other fully operational RCRA treatment units applied to the TVS demonstration. However, the testing itself was designed to encompass relevant elements of a RCRA regulatory trial burn. The original plan was to eventually use the TVS as a RCRA permitted treatment facility. The project testing included three phases: operations acceptance testing at Erwin, Tennessee in July 1995, shakedown testing at Clemson University on waste surrogates in March 1996, and performance of the subject demonstration testing at the ETTP, Oak Ridge, Tennessee, in 1996 and 1997.

An off-gas collection hood above the melter routes gases evolved from the treatment zone to an off-gas treatment system. The Anderson 2000 modular off-gas treatment system, which operates at a slight vacuum, uses water quenching, packed-bed scrubbing of acid gases, venturi scrubbing, mist elimination, reheating, and final particulate filtration. It was assumed that all mercury would be released from the melt to the off-gas system. Testing was not planned to include mercury-contaminated wastes and the off-gas system would have to be upgraded or mercury removed by pretreatment to control mercury emissions if mercury contaminated waste was to be treated.

The treated off-gas was released via a 15-m (50-ft) high stack with provisions for U. S. EPA approved particulate and gas sampling. Stack velocity was determined based on EPA Reference Method 2 measurements taken every other 12-hour shift. Stack effluent parameters of temperature, pressure, moisture content, and gas molecular weight were required data for calculating velocity, volumetric flow rates, pollutant mass emissions, and isokinetics.



Total particulate emissions were determined by EPA Method 5 with continuous isokinetic sampling for radioactive particulates representative of NESHAPs required monitoring (continuous sampling and biweekly analysis of collected particulate). All filters, probe washes, and blank reagents were analyzed for radionuclides using alpha spectroscopy counting, liquid scintillation counting, and gamma spectrometry. Effective dose equivalent (EDE) calculations based on actual measured values show that release values for the TVS are significantly less than those predicted by the original modeling calculations. Based on actual stack emission measurements, Tc-99, Th-228, and U-234 contributed 26.7, 31.3, and 13.3%, respectively to the total radionuclide particulate emissions. The actual waste streams fed to the unit and the APCS removal efficiencies for radionuclides will impact radionuclide emissions.

EPA Method 29 determined emissions of metals. Because of the very low halogenated organic contaminant levels and the high CO₂ off-gas content due to the decomposition of carbonate glass additives, certified destruction and removal efficiency (DRE) and dioxin emission tests were not planned in this initial test phase. TVS treatment of waste streams containing volatile and semivolatile organics would require upgrades to control the destruction and potential releases of these contaminants (by addition of a secondary combustion chamber ahead of the off-gas treatment system).

Continuous monitoring of the stack radionuclide emissions demonstrated that these emissions were well under the emissions limits specified for the system. The calculations based on measured values showed that release values for the TVS were significantly less than predicted by the original modeling calculations. Further testing would be required to determine if the system were capable of meeting the forthcoming MACT standards for emissions from hazardous waste combustors if it is determined that these standards are applicable.

The additional regulatory activities for the TVS demonstration activities conducted at ETTP included:

- NEPA documentation included approval under a categorical exclusion for a field demonstration of the TVS. However, conversion of the TVS to a RCRA permitted treatment facility would be expected to require an Environmental Assessment.
- An evaluation of radionuclide emissions was conducted pursuant to the Title 40 CFR Part 61 Subpart H National Emission Standards for Emission of Radionuclides other than radon from DOE facilities (radionuclide NESHAPs). The evaluation determined that continuous stack emission monitoring was required because of a potential EDE of > 0.1 mrem/year to the maximum exposed individual (MEI). An application for a NESHAPs Permit to Construct was submitted to EPA; however, approval from EPA was not required because the actual emissions of radionuclides were calculated to result in an MEI EDE of < 0.1 mrem/year. Request for concurrence with this evaluation was submitted to EPA in February 1996. In April 1996, EPA agreed with the evaluation and did not require formal approval to construct a NESHAPs source. In conformance with 40 CFR Part 61.93(b), the TVS was required to continuously monitor the effluent stream and all radionuclides that could contribute greater than 10% of the potential EDE.
- An application for a Permit to Construct a new air contaminant source was submitted to the TDEC in February 1996 and the permit issued on May 29, 1996 with an expiration date of May 1, 1997. A permit renewal request submitted in April 1997 was approved, renewing the permit to May 1, 1998, without changes. The TVS is included in the Title V permit application for ETTP.
- In July 1995, a RCRA research, development, and demonstration (RD&D) permit application was submitted to the TDEC, which subsequently determined it did not have the authority to grant this permit.
- An application for a Class III Modification to RCRA Permit TNHW-056 (RD&D permit) was then submitted to the TDEC in April 1996, including closure procedures.
- A TA request to allow site preparation, equipment assembly, and equipment shakedown activities using surrogate wastes was made in conjunction with the Class III Modification request and approved in 1 week by TDEC.
- A request to the TDEC for a TA to proceed with early assembling of the TVS was approved in June 1996.
- A request to the TDEC for a TA to proceed with cold testing using nonradioactive surrogate wastes was approved in July 1996.



- A request to the TDEC for a TA to proceed with actual mixed waste testing was approved in October 1996 but contained numerous requirements that could not be met by the demonstration project. These requirements resulted in a decision to shut down the TVS project until operating issues were resolved. A revised TA agreeable to all parties was subsequently negotiated and issued on July 22, 1997, with an effective date of July 23, 1997. The final TVS demonstration with B&C and CNF pond sludge was conducted under this TA.
- Because of the size and planned throughput of the unit, the Spill Prevention Control and Countermeasure (SPCC) Plan for the ORNL K-25 Site, K/HS-338 addressed potential spills associated with operation of the unit.

Analyses of the glass included TCLP testing. A modified TCLP was developed for the vitrified product. The modifications were designed to minimize the waste generated by the test. Additional testing would be required to determine if applicable revised LDR treatment standards for toxicity characteristic metals would be met. If different waste streams are fed than those fed in these demonstration tests, specific treatability studies would need to be performed to demonstrate that the applicable LDR treatment standards, including the applicable UTS for underlying hazardous constituents, would be met by the vitrified product.

A comparison of general regulatory issues for TVS versus an alternative nontransportable, nonthermal technology would include consideration of potential emissions to air during high temperature thermal processing, and the need for requalification of the process system after transportation of the system to a new site. There may be significant differences in the approaches used by different states to regulate a TVS. However, difficulties could occur that are similar to those encountered for the TVS at ETPP in regard to negotiation of the detailed control and monitoring requirements for potential emissions to air. Such difficulties would not be expected to occur for an alternative nonthermal process such as cement stabilization.

Safety, Risks, Benefits, and Community Reaction

Eight risk areas were evaluated and assessed independently for the level of risk as associated with the TVS: (1) acceptable (to stakeholders), (2) complete (ready for use), (3) correct (technical correctness), (4) cost (effectiveness to use), (5) permitable (ease of permitting), (6) safe, (7) sponsored (committed sponsorship), and (8) timely (to meet schedules).

The risk values, developed for the MWFA developed technology processes, have been derived from the eight top-level requirements defined in the MWFA Systems Requirements Document. A complete description of the methodology and a detailed definition of each risk element, the event scenario, and the basis for assigning consequences and probability factors are included in Appendix C. The Principal Investigator and the Product Line Manager involved with the TVS facility collected the data that were used as the basis for the risk assessment. A three-person team (representing the regulatory, science and technology, and public perspective of the MWFA) evaluated the material presented by the Product Line Manager against the criteria. This team then assigned a category to the evaluation.

Correct: This risk category is rated as moderately high. The targeted volume of waste to be treated (about 20 % of the current inventory) is high and the risk associated with a decision to proceed with the vitrification would be substantial if it were incorrect. For this process to be effectively used, a large volume of waste is required. Multiple waste stream types have been tested in the TVS.

Cost: This risk category is rated as moderately high. The targeted volume of waste to be treated (about 20 % of the current inventory) is high. For this process to be effectively used, a large volume of waste is required. The cost projections presented in this report are based on data from multiple demonstration campaigns.

Permitable: This risk category is rated as moderate. The treatment process is complex due to the process control and the off-gas systems. The development team obtained a TA to treat the 16,000 lb of waste, and have involved the regulators during the development and demonstration process.



Safe: This risk category is rated as moderate. The hazardous chemicals added to, and generated by the TVS are less than the reportable quantities. The system is an energetic system because the process operates at higher than ambient temperatures and pressures.

Sponsored: This risk category is rated at moderately low. Only limited data sets detailing the performance of the process are available from the Principal Investigator. The Waste Management Group at ORNL made a financial commitment to the demonstration of this process.

Complete: This risk category is rated as low. Deployment of the TVS at another site will require development and demonstration in two areas: the qualification of the process for use on the new site's waste streams, and the correction of any problems arising from transporting the system to the host site. The TVS, using a temporary authorization, completed the intent of a treatability study.

Acceptable: This risk category is rated very low. All identified concerns raised by interested and affected parties have been explained by providing additional information. These interested and affected parties also view the use of the TVS as a solution to an important problem, with little or no impact on their quality of life.

Timely: This risk category is rated very low. No milestone in a Consent Order is currently tied to the use of this process, so none will be missed. The development and demonstration activities have been completed with the known end-user schedule requirements from the ORNL Site.

The siting of a mixed waste thermal vitrification facility near communities will involve public input. Stakeholders may be concerned about the type, toxicity, and amount of emissions to be discharged to the atmosphere and the final disposal site for the glass waste form. However, past communication with stakeholders in regards to these issues indicate that vitrification is a favorable technology because it creates a relatively low volume of final waste, which is also highly durable.

The MWFA Tribal and Public Involvement Resource Team initiated activities to involve and gather stakeholder issues, needs, and concerns about stabilization technologies, including ex situ vitrification. These activities included reviews, articles, and presentations. Following are general stakeholder issues and concerns regarding stabilization methods found in public reports (specific sources and comments and related MWFA stakeholder activities can be found in Appendix D).

Stakeholders have expressed concerns regarding the current baseline technology, cementation, to stabilize various mixed waste streams. These concerns include the potential for an increase in waste volume and the durability of the waste form. One of the major advantages of a glass final waste form, as compared to a grouted or cemented waste form, is the decreased leachability and increased structural stability. Glass waste forms are expected to be more stable over longer periods due to the corrosion resistance of glass. However, devitrification of glass can occur over time periods involving thousands of years.

Stakeholders expressed concerns with increasing the volume of a waste and prefer to minimize waste generation. The vitrification process realizes volume reductions over cementation processes currently used to stabilize waste. In addition, land disposal of the nonleachable glass waste form has the potential to be more cost-effective due to the lower waste volume if sufficient quantities are treated at relatively high throughputs.

Another issue brought forth by stakeholders is the preference for onsite treatment. This technology has the capability to be transported to another DOE site for use.

Stakeholders may have concerns with the high temperature and relative complexity of the system. It may be necessary for end users to explain worker safety practices and the operation of the system. The leak of molten glass from the TVS that was caused by the original refractory construction did concern some stakeholders. However, refractory redesign and reconstruction along with changes in operating procedures have reduced the risk of future leaks.

Another issue regarding vitrification is the potential for air emissions. Currently, no "real time" monitoring devices are available for multiple metals, mercury, and dioxins. Concern centers around the release of these volatile contaminants. Stakeholders require that a technology not increase the mobility of contaminants it is designed to remediate. If suitable off-gas treatment is available, as was the case with the TVS, this concern can be alleviated.



Lastly, the MWFA Tribal and Public Involvement Resource Team facilitated Tribal and public involvement by issuing an article in the quarterly newsletter highlighting TVS and held a focus group meeting at ORNL on off-gas monitors for emissions. Details are provided in Appendix D.



SECTION 7

LESSONS LEARNED

Technology Selection Considerations

Owners of mixed waste and potential technology end users have many alternative stabilization methods available to them, including vitrification processes such as the TVS. In choosing among the various applicable options, many factors are involved including, but not limited to: long-term storage and disposal cost, short-term capital and operating cost, extent of development required, ease of permitting, extent of volume reduction, ease of operation, availability of equipment, and stakeholder acceptability. It is these factors that are usually considered most important in evaluating vitrification against its baseline and competing technologies.

Design Issues

Before an end user deploys the TVS or a similar TVS technology for mixed waste vitrification, the following list of recommended modifications, additions, and design changes are to be considered:

- Before actual treatment, the end user will be required to do development activities at the pilot scale including treatability studies with the actual waste material. These activities are necessary to produce the ternary phase diagram and identify appropriate parameter ranges to control the quality of glass.
- The end user should analyze the impact of increasing feed batch sizes above those used for the demonstration (approximately 850 lb). This will lower operating and analytical costs and feed a more homogeneous mix to the melter.
- The end user should ensure the feed system is suitable to the mixed waste to be treated and make modifications as appropriate.
- The end user should consider recycling sludge from the scrubbing system in the Off-Gas Module back to the Melter Module. This will limit the burden on secondary waste treatment.

Other requirements of the end user involve specific site preparation and permitting and are addressed in other sections of this report.

Implementation Considerations

To successfully implement the TVS facility and/or its associated technology requires potential end users to consider several process-related factors as well as logistics involving available support systems.

Before melting a given waste stream in the TVS facility, treatability studies with the target waste or surrogate waste are highly recommended. This development is essential to establish process control parameters since vitrification technology can be extremely sensitive to changes in waste feed chemistry. Changes in additive amounts and process temperature can easily change the melt viscosity and oxidation state as well as the solubility limits of some of the oxides. Consequences of these changes can be drastic. Examples include insufficient or poor glass pouring behavior, corrosion of the refractory, corrosion of the electrodes, precipitation of unwanted crystalline phases, and devitrification. The latter two effects can form accumulations in the melter. Therefore, complete characterization of the candidate waste stream is essential before initiating the development effort. The makeup of the waste will indicate what glass formers are already present in the waste and what additional glass stabilizers and fluxes need to be added to place it in the glass forming region of the glass system applicable for the waste type. In addition, characterization will identify any problem constituents such as phosphates, halides, volatile metals, free metals, or reducing



organics that may require additional development to identify additives to mitigate their foaming effects.

In terms of logistics, potential TVS end users need to consider the following capabilities and their associated hardware into the currently integrated vitrification system:

- Temporary supplemental waste sorting and transporting system for feeding of troublesome waste to the TVS Feed Preparation Module.
- An available treatment system for the secondary liquid and solid mixed and hazardous waste to be generated. Of unique concern is the scrubber blowdown solution from the melter off-gas system.
- Onsite analytical services with quick turnaround to determine glass product characteristics and validate melter performance. These services should include capabilities for sample preparation and be equipped with inductive coupled plasma-atomic emission spectrometry, X-ray diffraction, phase microscopy, and X-ray fluorescence.
- A temporary/interim storage location for the containerized glasses of waste.

Technology Limitations and Needs for Future Development

The TVS process is limited in several ways, including the type of mixed waste media that can be fed to and effectively vitrified in the melter. The TVS is not designed to take large debris, containerized waste, combustible organic wastes, free metals, or wastes containing significant amounts of reducing hydrocarbons that cannot be oxidized by additives. Unique or specialized wastes such as pure chemicals, oxidizers, explosives, and/or compressed gas cylinders are also prohibited. In addition, waste streams with mercury and mercury compounds are not allowed, since the TVS is not permitted to accept these or any other highly volatile species, and the TVS off-gas treatment system is not currently equipped with the technology to capture mercury. In general, mixed wastes with large quantities of salts are not recommended since they can disrupt the required oxidation state balance in the melt and lead to refractory/electrode corrosion and foaming.

Other limitations of the TVS are a result of its capacity and configuration. Even though the TVS was constructed in modular fashion to support transportation, it is not easily transported. Over 13-tractor trailer "semis" were required to relocate the melter from the Clemson University test site to the demonstration site at ORNL's ETPP. Transportation can also lead to other difficulties, such as the extra maintenance necessary to retighten the melter refractory and ensure quality during melter module reconstruction. In addition, the TVS Feed Preparation Module is limited to only three additive hoppers. This implies that only a combination of three glass forming stabilizers, glass forming fluxes, and/or any other additive needed to ensure operation within the proper oxidation state of the molten pool is possible.

The melter can also be limited by permit constraints established to ensure that harmful constituents such as oxides of nitrogen (NO_x) and volatile metals are not released in appreciable quantities to the atmosphere. These constraints are usually established by the regulatory agency and may be tied to the specific waste feed rate of the melter. For example, during the actual demonstration with actual mixed wastes, feed rates were limited to 220 lb/h.

To mitigate many of these limitations, a number of future modifications to the TVS facility are suggested, some of which may require additional process development. The following is a list and brief description of the possible changes:

- Modifications to the Feed Preparation and Delivery Module. The addition of grinders screens, pulverizers, and dedicated waste sorting, repackaging, and homogenizing areas will maintain optimum waste throughput, increase the acceptability of presently unallowed waste types, and ensure predictable and uniform vitrification products. Redesign of the melter recirculation feed loop to better control the bleed rate to the melter, and to reduce the erosion of the loop material from the abrasive waste feed would also benefit the efficiency of the TVS. In addition, increasing the feed/bend tank capacity would better homogeneity and lessen sample analytical costs



- Off-Gas Treatment Modifications for Organics. The addition of off-gas treatment systems such as secondary combustors would allow the TVS to treat waste containing higher quantities of both halogenated and nonhalogenated volatile and semivolatile organics. Such systems would allow the TVS to operate as an incinerator, if the regulatory body requires the TVS to be permitted accordingly. This modification may require a new approach for adding oxidizing agents to the melter in order to control redox.
- Off-Gas Treatment Modifications for Mercury. The addition of supplemental off-gas treatment systems such as sorbents and dedicated scrub systems for mercury and mercury compounds would allow the TVS to treat wastes contaminated with this volatile and troublesome metal. In addition to effluent treatment, mercury pretreatment methods for the feed waste stream may also be required.



APPENDIX A

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APPENDIX B

TMS DATA ELEMENTS

This section provides reference and account tracking information associated with the TVS facility and past development. The Department of Energy-Headquarters (DOE-HQ) Technology Management System (TMS) tracking number is provided as well as the specific Technical Task Plans (TTPs).

The TTPs were contracts established between EM-50 and the investigators and developers of TVS. They provided the TVS development scope and MWFA resources to both the SRS and the ORNL ETTP.

The TMS # is 222 - Transportable Vitrification System (TVS)

Technical Task Plans:

SR06MW40	Vitrification Process Support
SR16MW41	Transportable Vitrification System at ORNL
SR16MW42	Vitrification Process Limits Testing and High Temperature Demo on Actual Waste
OR16MW41	TVS Demonstration Support
SR16MW41	Transportable VIT System at ORNL
SR16MW42	Vitrification Process Limits Testing and High Temperature Demo on Actual Waste

MWFA Product Line: Off-Gas Components #8 and Stabilization #4



APPENDIX C

RISK ASSESSMENT METHODOLOGY

Risk has been measured for eight of the system requirements as defined in the Mixed Waste Focus Area (MWFA) Systems Requirements Document.

Technically Correct (**Correct**)

The MWFA shall deliver treatment technologies that are technically correct. Operable treatment systems, which incorporate such treatment technologies, shall be able to: (1) treat target waste streams identified in Federal Facility Compliance Act (FFCA) Site Treatment Plans (STPs), and, (2) treat wastes to meet Environmental Protection Agency (EPA) treatment standards (and Toxic Substance Control Act or state-regulated treatment standards, where applicable) and comply with disposal facility Waste Acceptance Criteria (WAC).

Technically Complete (**Complete**)

Treatment technologies delivered by the MWFA shall be demonstrated to function as described, and shall be described in sufficient detail so that they may be incorporated into a detailed system design of a mixed low-level or mixed transuranic waste treatment system without further development.

Acceptable to Stakeholders (**Acceptable**)

The MWFA shall deliver mixed waste treatment technologies that are acceptable to the stakeholders.

Note: The term "stakeholders" means all those who have an interest in the outcome of the MWFA program except the DOE and DOE contractors who have a direct and immediate interest or involvement in the MWFA. Stakeholders include: Tribal governments, members of the public, federal, state, and local agencies, universities, and industry.

Acceptable to an End User (**Sponsored**)

The MWFA shall deliver mixed waste treatment technologies to end users committed to pursuing the use of those treatment technologies in mixed waste treatment systems.

Permitable

The MWFA shall deliver mixed waste treatment technologies along with sufficient data to show that there are no probable technical reasons to prevent receiving a permit to implement the technology in an operational treatment system. The permit process will be facilitated by involvement with national regulatory organizations such as National Technical Workgroup (NTW) on Mixed Waste Treatment and Interstate Technology and Regulatory Cooperation Subgroup (ITRC). This will include working with the regulators to improve technologies and/or a facility's ability to obtain a permit.

Safe

The MWFA shall deliver mixed waste treatment technologies that can be incorporated into a treatment system and safely operated.

Timely

The MWFA shall deliver mixed waste treatment technologies to enable treatment systems using these technologies to be designed, built, and operated in time to meet treatment schedules in the FFCA STPs and negotiated in Consent Orders.

Cost

The "delta" refers to the cost of implementation by an end user when compared to the cost analysis included in the Technology Performance Report (TPR). The more closely the cost of implementation compares with cost as reported in the TPRs, the smaller the consequence to the end user of the technology.



Each of the eight system requirements will be addressed independently. Events that can lead to negative consequences relative to implementation of a technology will be identified and assigned to each system requirement. These events will be referred to as “risk factors.” Each technology will be evaluated independently and relative values for consequences and probability will be assigned to each of the events. The risk factors will be plotted on a risk chart as shown in Figure C-1.

The numbers in the matrix elements, 1 through 9, represent the risk with the following scale: 1=very low risk, 2 and 3=low risk, 4, 5, and 6=moderate risk, 7 and 8=moderately high risk, and 9=very high risk. By assigning numerical values to the qualitative matrix elements, total risk can be summed. By assigning the lower values to probability, more emphasis is placed on consequences.

Criteria have been defined for each risk category to allow the user to, as quantitatively as possible, determine the probability and consequence measures to be applied for determination of risk in accordance with the risk matrix, Figure C-1.

Figure C-1 - Risk Matrix

Consequence	High	6	8	9
	Med	3	5	7
	Low	1	2	4
		Improbable	Unlikely	Likely
		Probability		

Permittable

Permit application is rejected based on regulations that became effective after development of the technology.

The consequences of this scenario will be:

Low if The treatment process is simple.

Medium if The treatment process is complex.



High if The treatment process is highly complex.

The probability of this scenario occurring will be:

Improbable if An applicable permit has been received.

Unlikely if Regulators have maintained interaction with developers on this technology during development and demonstration.

Likely if A permit application has already been rejected for this technology.

Complete

Technology is insufficiently mature to incorporate into a system without additional engineering data.

The consequences of this scenario will be:

Low if The technology can be deployed without the need for additional testing.

Medium if The technology can be deployed with limited additional testing and documentation.

High if The technology requires significant additional development and/or testing to deploy.

The probability of this scenario occurring will be:

Improbable if The technology successfully meets Stage 5 requirements for full system functionality and has successfully conducted a treatability study.

Unlikely if The technology successfully meets Stage 5 requirements for full system functionality and has conducted successful demonstration(s) with surrogate wastes.

Likely if The technology successfully meets Stage 5 requirements for full system functionality but demonstration/testing program is incomplete.

Acceptable

Native American Tribes and/or public interest groups resist implementation of the technology at DOE sites.

The consequences of this scenario will be:

Low if Concerns can be addressed by providing additional information about the technology's performance.

Medium if Concerns center on the performance of the technology; relatively minor modifications to the technology can address the needs and concerns.

High if Major modifications to the technology are required to address concerns about the performance and ability to solve the problem.

The probability of this scenario will be:

Improbable if The affected Tribes and public perceive implementation of the technology as resolving an important problem at their site with minimal or no impact to their quality of life, or have not expressed any concerns.

Unlikely if The affected Tribes and public perceive implementation of the technology as solving an important problem but having a negative impact on the quality of life.

Likely if The affected Tribes and public perceive implementation of the technology will not solve an important problem at the site and is perceived to have significant negative impact on the quality of life.



Timely

The technology is not available for implementation by the STP or Consent Order date.

The consequences of this scenario will be:

Low if	The delay in the availability of the technology will not result in missing a milestone in a Consent Order.
Medium if	The need dates for the Consent Order can be renegotiated to accommodate the delay in availability of the technology.
High if	The unavailability of the technology results in missing key milestones in Consent Orders at multiple sites.

The probability of this scenario will be:

Improbable if	Technology development/implementation activities are completed within end-user schedules.
Unlikely if	Need dates identified accommodate any minor delays in technology development activities.
Likely if	The technology does not meet end-user schedules.

Cost

Operational costs are higher than projected.

The consequences of this scenario will be:

Low if	The volume of the targeted waste is low.
Medium if	The volume of the targeted waste is fairly small.
High if	The volume of the targeted waste is very large.

The probability of this scenario will be:

Improbable if	Projections of the technology's cost are based on data from multiple campaigns.
Unlikely if	Projections of the technology's cost are based on data from only one campaign.
Likely if	There are no actual cost data for the technology on the targeted waste.

Sponsored

No end-user or commercial entity selects the technology for implementation.

The consequences of this scenario will be:

Low if	Multiple data sets detailing the technology's performance on targeted waste are available.
Medium if	Only limited data are available detailing the technology's performance on targeted waste.
High if	No data are available detailing the technology's performance on the targeted waste.

The probability of this scenario will be:

Improbable if	Multiple licensing agreements or financial commitments have been made.
Unlikely if	A single licensing agreement or financial commitment for the technology has been made.



Likely if There have been no commitments made or interest shown in the use of the technology.

Correct

Operable treatment systems, which incorporate this technology, are not applicable to target wastes.

The consequences of this scenario will be:

Low if The volume of targeted waste to be treated is low.

Medium if The volume of targeted waste to be treated is fairly small.

High if The volume of targeted waste to be treated is very large.

The probability of this scenario will be:

Improbable if The technology developed was tested against multiple waste types.

Unlikely if The technology developed was tested against only one waste type.

Likely if The technology developed was not tested against a targeted waste type.

Safe

System failure adversely impacts the health and/or safety of a collocated worker, the environment, or a member of the public.

The consequences of this scenario will be:

Low if: Hazardous constituents added or generated by the system are less than the reportable quantities shown in 40 CFR 302.4 and 40 CFR 355, Appendix A.

Medium if: Nominal reportable quantities of hazardous constituents shown in 40 CFR 302.4 and 40 CFR 355, Appendix A, are added or generated by the system.

High if: Hazardous constituents in quantities 10 times or greater than those listed in 40 CFR 302.4 and 40 CFR 355, Appendix A, are added or generated by the system.

The probability of this scenario will be:

Improbable if: The system is a benign process, difficult to combust with no natural gas or fuel sources present.

Unlikely if: The system is a moderately energetic process with natural gas or fuel sources present.

Likely if: The system is an energetic system (high temperature and/or pressure); large amounts of flammables or pyrophorics.



APPENDIX D

PUBLIC AND TRIBAL INVOLVEMENT RECORD

The MWFA's strategy to involve Tribes and members of the public is outlined in the MWFA Tribal and Public Involvement Plan and can be obtained on the MWFA homepage at <http://wastenot.inel.gov/mwfa/>.

Stakeholder Comments Database

In addition, the MWFA has assembled a Stakeholder Comments Database that is accessible through the MWFA homepage address. A keyword search was conducted using vitrification and stabilization, and the following comments were identified:

1. **Source:** Savannah River Site Waste Management Final Environmental Impact Statement. July 1995. DOE/EIS-0217.
2. **Comment:** Stakeholders generally support the vitrification of high-level wastes at the Savannah River Site's Defense Waste Processing Facility.
3. **Source:** Laura Belsten, EG&G Rocky Flats Community Relations Department, Community Relations Survey, November 25, 1994.
4. **Comment:** Specific technologies in which respondents are interested include polymer stabilization, microwave solidification, vitrification processes for plutonium, liquid stabilization, and the Raschig ring change-out process.
5. **Source:** DOIT Committee Stakeholder Participation Roundtable, Denver, September 28--30, 1994.
Comment: [Stakeholder processes] should provide for broad . . . assessment and prioritization of promising technologies for funding and deployment; just commenting on a handful of existing demonstration projects is too "low stakes" for the major policy actions needed.
6. **Source:** Tribal and Stakeholder Principles for Use in Evaluating Technology Systems for Mixed Low-Level Waste Treatment.
Comment: In developing technologies for application by the MWFA, the effects on human health and the environment should be minimized, including minimizing exposure to workers, potential for release of hazardous and radioactive materials from final storage/disposal products, and the potential for accidents and incidents.
7. **Source:** DOE Report on Rocky Flats Summit II, January 19--20, 1996.
Comment: Storage technology of low-level radioactive waste should include waste minimization and treatment to eliminate, rather than simply stabilize waste.

Reviews

The MWFA assembled a Technical Requirements Working Group (TRWG); which is a stakeholder group that consists of eight technically trained or conversant members, capable of representing varied Tribal and public perspectives. Some members are participants in specific DOE site stakeholder groups. The TRWG's objective is to assist MWFA technical staff in transforming or integrating site-specific issues, needs, and concerns into the Technology Development Requirements Documents (TDRDs), and providing Tribal and public perspectives to technical staff for identifying and resolving technical issues. The TRWG reviewed and provided recommendations to the MWFA on changes to the Radionuclide Partitioning TDRD (**copy in file**). Those changes were reviewed and incorporated into the TDRD.

Press Releases and Articles

The MWFA quarterly newsletter, March 1997, Volume 1, Issue 1, contained a story titled "Mixed Waste Focus Area Melter Strategy" and an update on the status of the Transportable Vitrification System. The MWFA newsletter has a distribution list that contains DOE-HQ; DOE-ID; EM-30, 40, and 60 personnel; the Community Leaders Network; the TRWG; the National Technical Workgroup; the Interstate Technology and Regulatory Cooperation group; and Site Technology Coordination Groups.



Presentations

The project management team at Oak Ridge National Laboratory (ORNL) gave a presentation to the Technology Working Group of the ORNL Site Specific Advisory Board. In addition, the Tennessee Department of Environment and Conservation DOE oversight office made four to five informational visits on TVS.

The MWFA held a focus group meeting in July 1997 with members of the Local Oversight Committee, Site Specific Advisory Board, and other members of the public. A presentation was given on TVS outlining the demonstration and progress to date. The individuals present viewed the volume reduction results as a positive aspect of the technology.



APPENDIX E

ACRONYMS

APCS	air pollution control system
BTU	British Thermal Unit
CAA	Clean Air Act
CESE	Clemson University Environmental Systems Engineering
CETL	Clemson Environmental Technologies Laboratory
CFR	Code of Federal Regulations
CNF	Central Neutralization Facility
DOE	Department of Energy
DOE-HQ	Department of Energy – Headquarters
DRE	Destruction and removal efficiency
EDE	Effective dose equivalent
EM	Environmental Restoration and Waste Management
EPA	Environmental Protection Agency
ETTP	East Tennessee Technology Park
FFCA	Federal Facility Agreement Compliance Act
HEPA	High-efficiency particulate air
HLW	High-level waste
INEEL	Idaho National Engineering and Environmental Laboratory
ITRC	Interstate Technology and Regulatory Compliance Subgroup
ITSR	Innovative Technology Summary Report
LDR	Land disposal restriction
LLW	Low-level waste
LMES	Lockheed Martin Energy Systems
MACT	Maximum Achievable Control Technology
MEI	Maximum exposed individual
MLLW	Mixed low-level waste
MWFA	Mixed Waste Focus Area
NAAQS	National Ambient Air Quality Standard
NESHAPs	National Emission Standard for Hazardous Air Pollutants
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
NSPS	New Source Performance Standards
NTW	National Technical Workgroup
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology
PCT	Product Consistency Testing
PLC	Programmable logical controller



RCRA	Resource Conservation and Recovery Act
RD&D	Research, development, and demonstration (RCRA Permit Class)
RFETS	Rocky Flats Environmental Technology Site
SLS	Silica-lime-soda glass
SPCC	Spill Prevention Control and Countermeasures
SRS	Savannah River Site
STP	Site Treatment Plan
TA	temporary authorization (RCRA Permit Class)
TCLP	Toxicity Characterization Leaching Procedure
TDEC	Tennessee Department of Environment and Conservation
TDRD	Technology Development Requirements Document
TMS	Technology Management System
TPR	technical procedure
TRWG	Technical Requirements Working Group
TSDF	Treatment, Storage, and Disposal Facility
TTP	Technical Task Plan
TVS	Transportable Vitrification System
UTS	Universal Treatment Standard
WAC	Waste Acceptance Criteria
WSRC	Westinghouse Savannah River Company

